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LONG TERM DECOMPOSITION OF TEMPERATE FOREST LITTER

Charles A. McClaugherty

Department of Biology
Clarkson University
Potsdam, NY 13676, USA

ABSTRACT

Mass losses and nitrogen dynamics are described for twelve temperate forest litter types decomposing in litter bags in south-central Wisconsin, USA. Decomposition rates of foliage, wood, bark and root litters declined during the period indicating that a simple negative exponential model is inappropriate for long-term decay. The percent of initial mass remaining after five years differed greatly among the litter types, ranging from 17% for red maple (*Acer rubrum* L.) wood to 75% for hemlock (*Tsuga canadensis* (L.)Carr.) bark. Nitrogen was strongly retained in far-decomposed litter with more than 70% of the initial nitrogen remaining in litter when less than 25% of the initial mass remained. The study points out the need for additional research on the late stages of decomposition, the dynamics of nitrogen and other nutrients during those late stages and on the decomposition of non-foliage litters.

INTRODUCTION

Studies of litter decomposition in forests often focus on foliage litter and examine only one or two years of decomposition. As a result, predictive models of forest production that include decomposition and nutrient release processes must be based on incomplete knowledge. In the context of intensive forestry, logging residues are often composed of wood, bark and roots, materials for which the patterns of decomposition are not well known. At the same time, most residues are be short-term sinks for nitrogen and some other nutrients and the majority of the nutrients required for regeneration of the forest must come from older soil organic matter. This report demonstrates that decay rates and nutrient release from litter during later stages of decay can not be simply extrapolated from short-term studies and indicates areas where additional work is needed.

STUDY SITE

The study was conducted on Blackhawk Island in the Wisconsin River, south-central Wisconsin, USA (43 deg 38' N, 89 deg 47' W) at an altitude of 280 m. Thirty-year mean annual precipitation was 799 mm based on records at the Wisconsin Dells weather station located on the Wisconsin river 2 km south of the site. Average actual evapotranspiration (AET) (Thornthwaite and Mather 1955,1957) for the same period was 605 mm. Soil temperatures at 10 cm were at or near 0 C from mid-December until mid-March.

Decomposition was studied in five forest communities on Blackhawk Island (McClaugherty et al. 1985), but only the results from the sugar maple (Acer saccharum Marsh) site will be presented here. This site was dominated by sugar maple with lesser amounts of basswood (Tilia americana L.) and red oak (Quercus rubra L.). The forest was a mature edaphic climax situated on a silty clay loam Alfisol. More details on the soils, geology and vegetation are given by Pastor et al. (1982).

MATERIALS

Twelve litter materials, all indigenous to Blackhawk Island, were selected for the study. These materials were chosen to represent a range of common temperate forest litter types. The litter types and their initial chemical and nutrient compostion are listed in Table 1. Chemical composition is often used as a predictor of decay rates (Berg et al. 1984, Melillo et al. 1982, Meentemeyer 1978) and the data are included here for reference. Foliage litter was collected from a number of 1 x 30 m screens spread on the forest floors of each stand during October 1980. Litter was collected within three days of falling and there was no precipitation during the collection period. Each foliage litter was collected only in the stand where it was the dominant species, except for red oak leaves, which were collected in the white oak stand. Bark and wood were collected from disease free trees which were felled within 5 km of the site. Bark was hand peeled and broken into chips of about 1 x 3 cm. Peeled logs, about 20-30 cm in diameter, were chipped with a pulpwood chipper into chips roughly 1 x 2 x 0.25 cm. Fine roots 0.5 to 3.0 mm diameter were collected from forest floor and A horizons. Sugar maple roots were collected adjacent to the sugar maple site and white pine roots were collected in a nearby white pine plantation.

Collected materials were air dried at 20-25 C to constant weight. Moisture content after air-drying ranged from 7.4 to 11.3 % but the range of variation within a litter type was less than 0.5%. Prior to air drying, fine roots were gently rinsed to remove adhering soil particles and apparently dead roots were discarded.

Samples of each litter type were weighed, enclosed in litter bags (see below) and placed in the field on November 3, 1980. Air-dry weight of all foliage litter samples was about 4 g, except for hemlock needles which were 2 g. Wood and bark

samples weighed 10 g and fine root sample weighed 2 g.

Table 1. Litters used in long-term decomposition study and their initial chemical composition. Scientific names: Sugar maple (Acer saccharum Marsh), Aspen (Populus grandidentata Michx.), White oak (Quercus alba L.), Red oak (Q. rubra L.), White pine (Pinus strobus L.), Hemlock (Tsuga canadensis [L.] Carr.), Red maple (A. rubrum Marsh.). EXT - polar + non-polar extractives; AS - acid soluble; AIS - acid insoluble; N - nitrogen; P - phosphorus. See method section for analytical definitions.

Litter	Initial Composition (Ash-free dry matter)				
	EXT	AS	AIS	N	P
FOLIAGE					
Sugar maple	44.8	43.1	12.1	0.83	0.10
Aspen	31.1	47.5	21.4	0.83	0.14
White oak	32.4	47.4	20.2	0.84	0.15
Red oak	30.0	45.2	24.8	0.82	0.12
White pine	32.8	44.7	22.5	0.44	0.06
Hemlock	35.8	39.6	20.6	0.83	0.08
WOOD					
Red maple	7.0	80.5	12.5	0.09	0.02
White pine	9.6	68.3	22.1	0.04	0.01
BARK					
Hemlock	20.8	40.3	38.9	0.30	0.04
Red maple	18.6	64.6	16.8	0.45	0.06
FINE ROOTS					
Sugar maple	18.5	47.7	33.8	1.67	0.23
White pine	25.2	49.5	25.3	0.93	0.15

METHODS

Litter bags were flat 15 x 15 cm pockets made of polyester fabric with a 0.1 mm mesh opening. Litter bags were incubated in the litter layer of the forest floor. Bags were located randomly within the stand except when the random location coincided with a tree stem or a perched log. Litters were also incubated in 2.0 mm mesh bags and in 0.1 mm mesh bags buried 5 cm in the mineral soil. The results of that study were similar to the results described here and are not described further. Litters were also incubated in other stands with similar results. A discussion of the first two years of that work has been presented by McClaugherty et al.(1985) and data have been published by Aber et al.(1984).

Four litter bags of each litter type were collected at predetermined intervals up to 3 1/2 years. After five years, fifteen bags of each species were collected. Following collection, litter bags and their contents were dried at 60 C

to constant weight. The contents of each bag were weighed and ground to pass a 1 mm mesh screen. Subsamples from each bag were analyzed for moisture (105 C for 48 hrs), ash (450 C for 8 hrs) and total nitrogen and phosphorus (Miller and Miller 1948, Technicon 1977). The amount of material remaining in the bags after two years of incubation was so small that samples were pooled by litter type for ash and nitrogen determinations.

Samples were analyzed for non-polar extractives using dichloromethane as the extractant (TAPPI 1976) and polar extractives using hot (100 C) water (TAPPI 1975). The extractive-free residue was separated into acid-soluble and acid-insoluble fractions using a two-stage digestion in sulfuric acid (Effland 1977). These two fractions approximate holocellulose and lignin, respectively, at least in the initial litter.

RESULTS AND DISCUSSION

Mass losses of the six foliage litters were similar to one another during the five year study (Figure 1a). Wood, bark and fine root litter, in contrast, did not follow a common pattern of mass loss (Figures 1b-1c). Fine roots decayed more slowly than any other substance except hemlock bark. The bark and wood litters differed greatly with red maple wood having the smallest percent of initial remaining after five years and hemlock bark having the highest percent remaining.

Although foliage litters appear to have a simple negative exponential decay pattern, they actually decay at a decreasing rate. If decay rate is constant, the calculated decay constants or "K" values would be nearly the same for any interval of decay. Decay constants for successive intervals of decay are given in Table 2. The decay constants are calculated on the basis of cumulative AET rather than time. This was necessary because the interval from 2 to 3 1/2 years included one summer and two winters whereas the interval from 3 1/2 to 5 years included two summers and one winter. The decay values were then normalized for time by dividing the cumulative AET during the interval by 605, the mean annual AET. The equation is thus:

$$\ln[M_{(t+1)}/M_{(t)}] = -k(CAET/605) \quad (1)$$

where M is mass at the beginning (t) and end (t+1) of the interval and CAET is the cumulative AET during the interval.

Table 2 clearly illustrates that decay rates declined during decay of foliage litters. In contrast, decay rates of red maple wood and hemlock bark remained approximately constant and the decay rate of white pine wood actually increased. This analysis of litter decay indicates that long-term decay rates for soil organic matter cannot be predicted solely from a knowledge of the initial decay rates of litter. In addition, litters other than foliage, even when incubated under identical conditions, may have very different patterns of mass loss. Non-foliage litters probably provide an input of organic matter to the soil of at least the same magnitude as foliage litters.

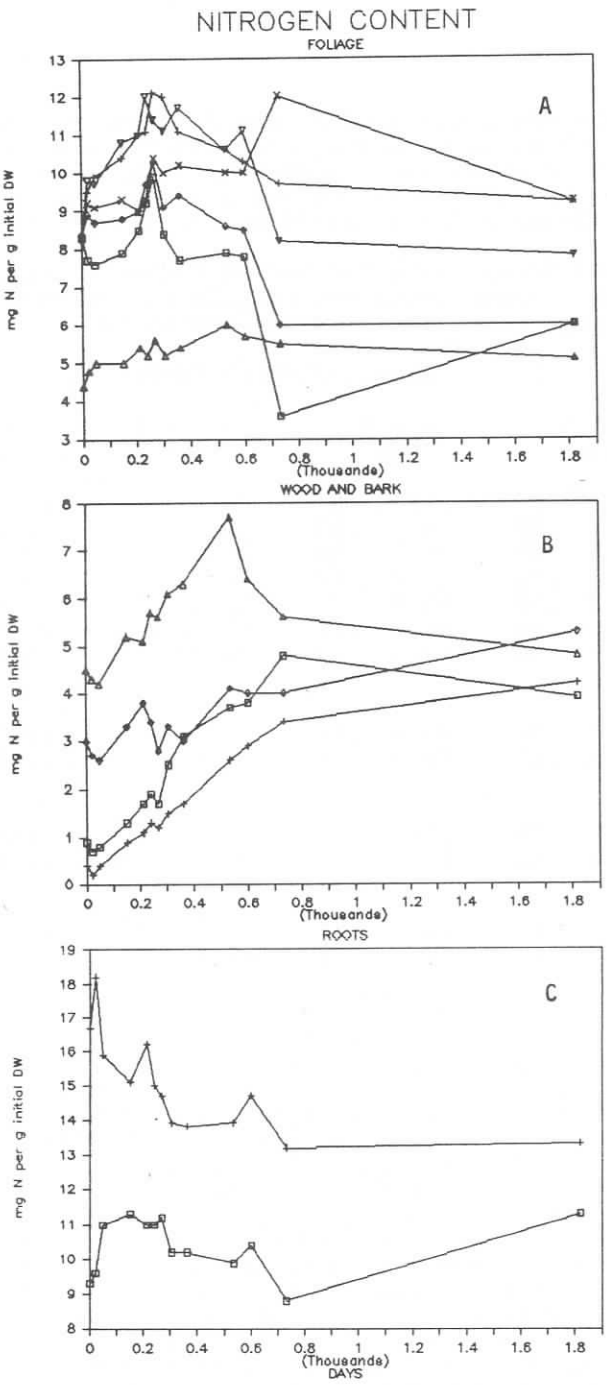


Figure 2. Absolute amount of nitrogen as mg per g initial dry weight for 12 forest litters incubated in litter bags in south-central Wisconsin, USA.
A: FOLIAGE (□) sugar maple; (+) aspen; (◇) white oak; (▽) red oak; (△) white pine; (×) hemlock.
B: WOOD AND BARK (□) red maple wood; (+) white pine wood; (◇) hemlock bark; (△) red maple bark.
C: FINE ROOTS (+) sugar maple; (□) white pine.

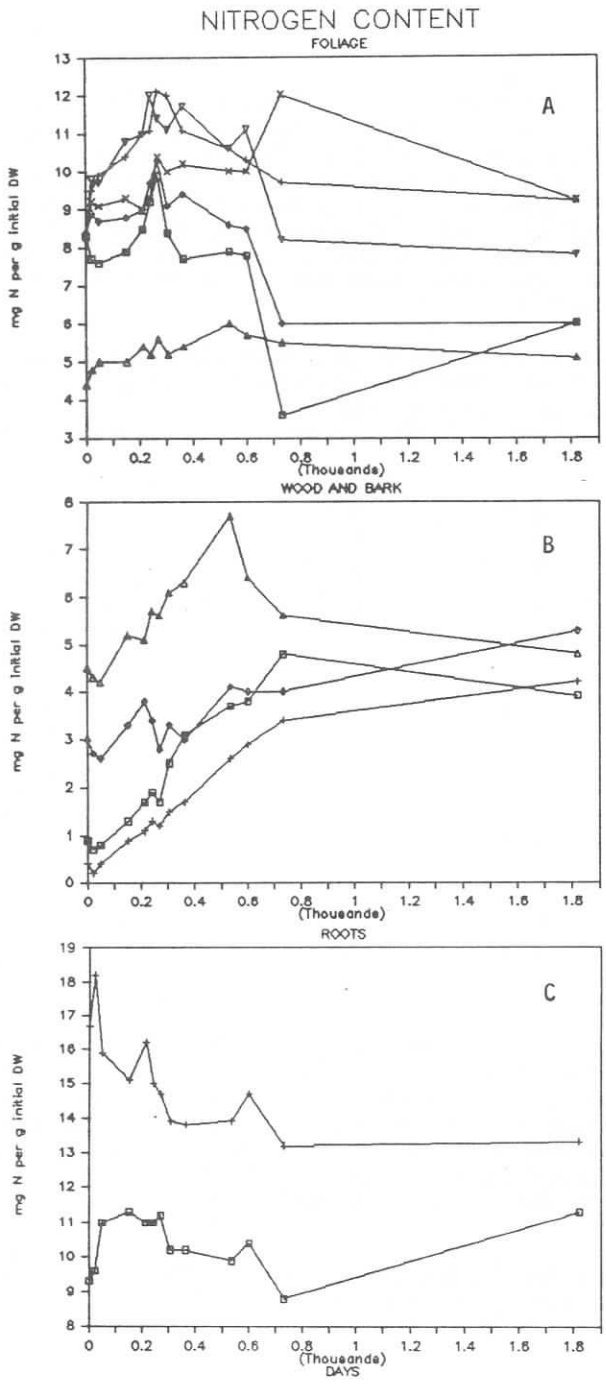
Our knowledge of the decay patterns of non-foliage litters and of the late-stages of decay of nearly all litters is limited. Therefore, attempts to model the response of forests to disturbance or various management regimes could be improved by increasing our knowledge and understanding of decomposition.

Table 2. Normalized decay rates for twelve litter types during five years of decay. Decay rates are calculated according to equation 1. PIR - percent of initial mass remaining.

Litter	Decay interval (years)							
	0 - 1		1 - 2		2 - 3.5		3.5 - 5	
Cumulative AET (mm)	605		605		643		1172	
FOLIAGE	PIR	K	PIR	K	PIR	K	PIR	K
Sugar maple	41.6	.88	24.6	.53	24.6	0	18.6	.15
Aspen	56.7	.57	44.7	.24	31.2	.34	27.2	.06
White oak	59.6	.52	35.2	.52	28.7	.20	20.2	.18
Red oak	59.2	.52	45.4	.27	32.9	.30	25.4	.13
White pine	64.1	.44	46.8	.31	40.5	.14	27.9	.19
Hemlock	69.7	.36	54.9	.24	40.8	.28	35.9	.06
WOOD								
Red maple	70.7	.35	46.4	.42	31.5	.37	16.8	.32
White pine	93.5	.07	70.5	.28	60.2	.16	28.4	.39
BARK								
Hemlock	95.1	.05	90.6	.05	89.0	.02	75.3	.08
Red maple	61.4	.49	40.5	.42	32.2	.21	20.1	.24
FINE ROOTS								
Sugar maple	84.6	.17	75.0	.12	70.0	.07	61.4	.07
White pine	78.5	.24	66.3	.17	56.1	.16	50.0	.06

Nitrogen is often the most limiting nutrient for forest productivity. Accordingly, many studies of litter decay have included an analysis of the nitrogen dynamics of the decomposing litter. Thus, similar to mass loss studies, nitrogen studies have concentrated on foliage litters during the first one to two years of decay. The majority of litters immobilize nitrogen during the early stages of decay. Eventually , the litters begin releasing nitrogen, making it potentially available for plant uptake. Even when the release of nitrogen begins, a given litter contains more nitrogen than it contained when it entered the soil. Mineralization must continue for some time until the litter is actually a net source of nitrogen to the ecosystem, or in other words, until cumulative net mineralization exceeds cumulative net immobilization. It is the behaviour of the litter in this stage of decay that determines the rate at which it contributes mineral nitrogen to the ecosystem.

Figures 2 a-c illustrate the absolute amount of nitrogen



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B: WOOD AND BARK (□) red maple wood; (+) white pine wood; (◇) hemlock bark; (△) red maple bark.
C: FINE ROOTS (+) sugar maple; (□) white pine.

contained in decomposing litter. All litters immobilized nitrogen during their initial decay. Some litters, notably wood and bark, continued to immobilize during the entire five year period. Sugar maple leaves release the largest amount of nitrogen, 2.3 mg per gram initial dry weight. This means that after sugar maple foliage had lost more than 80% of its initial mass (Table 2), it had lost only 28% of its initial nitrogen. Similar calculations have been made for all litter types and are presented in table 3.

Table 3. Absolute amounts of nitrogen initially and after five years of decay. Nitrogen amounts are listed as mg of nitrogen per g of initial ash-free dry weight

Litter	Initial N	N at 5 yrs	% of initial	change mg
FOLIAGE				
Sugar maple	8.3	6.0	72.2	-2.3
Aspen	8.3	9.2	110.8	+0.9
White oak	8.4	6.1	72.6	-2.3
Red oak	8.2	7.8	95.1	-0.4
White pine	4.4	5.5	115.9	+1.1
Hemlock	8.3	9.2	110.8	+0.9
WOOD				
Red maple	0.9	3.9	437.8	+3.0
White pine	0.4	3.4	1058.0	+3.0
BARK				
Hemlock	3.0	5.3	175.7	+2.3
Red maple	4.5	5.6	106.9	+1.1
FINE ROOTS				
Sugar maple	16.7	13.3	79.6	-3.4
White pine	9.3	11.3	121.5	+2.0

The results of this analysis indicate that most nitrogen release to the ecosystem will occur during very late stages of decay, perhaps after 3 to 5 years in temperate systems and with greater than 50% cumulative mass loss. It is thus important that we focus our research on these important later stages of decay if we are to successfully model organic matter and nitrogen dynamics as they relate to forest ecosystems.

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